Port of Açu: Climate Risks Assessment

EXECUTIVE SUMMARY

PORTO DO AÇU

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How to cite:
Porto do Açu Operações S.A. (2022). *PORT OF AÇU: CLIMATE RISKS ASSESSMENT - Executive Summary.*. https://esg.portodoacu.com.br/

Rio de Janeiro, May 2022

SUMMARY

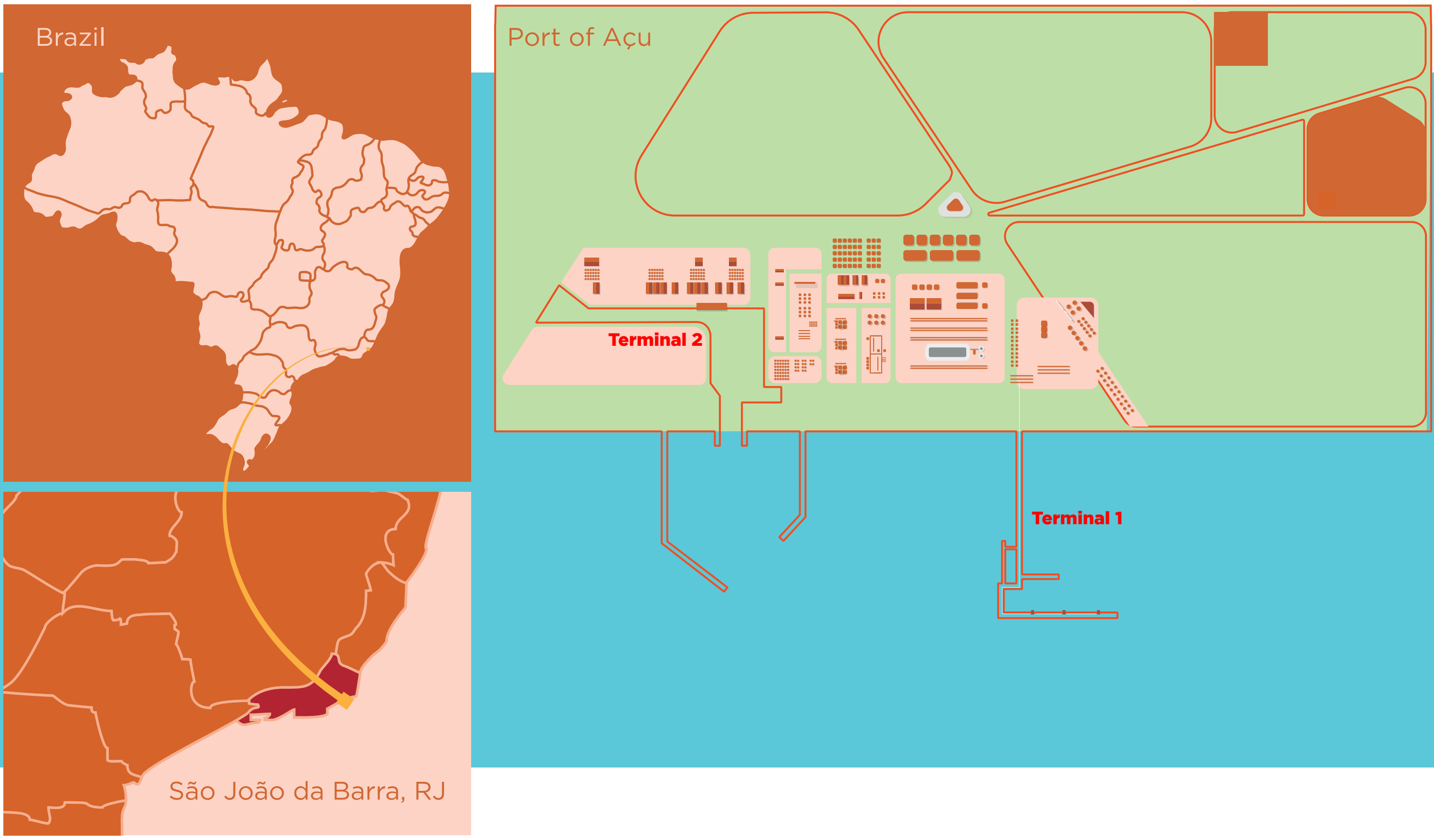
BACKGROUND

Under development by Prumo Logística S.A., a company of EIG Global Energy Partners and Mubadala Investment Company, Port of Açu is located at São João da Barra, in the northeast of Rio de Janeiro state, Brazil. Açu is the result of investments totaling US$ 4,5 billion and represents a port-industry complex with 100% private capital participation. Its administration is operated with the highest standards of efficiency and safety. Regarding aids to navigation, the port was the first in the country to have implemented maritime traffic services (VTS) and currently has buoys, lanterns and state-of-the-art meteoceanographic equipment.

The port started operating in 2014 and it comprises 10 private terminals organized within two main areas: Terminal 1 (T1 - offshore) handling iron-ore and crude oil and Terminal 2 (T2 - onshore) handling general cargo, dry bulk and also home to O&G offshore support bases, a LNG terminal and thermopower plants.

Port of Açu covers a total area of 130 km of which 90km is dedicated to port and industrial development and 40 km represent the Caruara Reserve, a natural reserve conservation unit.

Figure 1. Port of Açu Map



Aiming to ensure the orderly occupation and sustainable development of Açu, Port Administration has developed its Master Plan, which defines urban, economic, and environmental criteria aligned with municipal and state regulations with a horizon up to the year 2050. The defined criteria provide the guidelines for the location of different types of industries seeking possible synergies and guiding the Port's planning for the implementation of land infrastructure, maritime and port developments, such as dredging works, land access, water distribution, sanitation and energy. Also, according with its Strategic Planning, Açu aims to grow its operations through the development of low carbon businesses, consolidating Açu as a connection point to the rapid expansion of decarbonization worldwide.

By mid-2020, in accordance with its new Sustainability Strategy and climate change risk management best practices, Port of Açu started the studies to evaluate potential impacts of climate change effects on the Port's operations and infrastructure, focusing on the effects of changing sea level, winds, waves, and precipitation regimes.

The results, summarized in this report, show that the presently available projections indicate only limited changes in environmental climate conditions within the next few decades, concluding that the port location can be considered favorable from a climate change perspective. The results also indicates that possibly more relevant changes are projected to occur in the longer-term (i.e., 2070+) in mean sea level, wind, and precipitation conditions.

INTRODUCTION

Ports around the world are already experiencing the consequences of air and water temperature increases, rising sea levels and changes in seasonal precipitation, wind, and wave conditions. Many are also seeing more frequent and severe extreme events such as storms, heatwaves, and droughts. From a global perspective, the climate change effects associated with global warming are projected to escalate in the coming decades and may represent a significant risk to business, operations, safety, and infrastructure. Therefore, ports may be required to take urgent action to strengthen resilience and adapt to possible adverse changing conditions.

By mid-2020, the company approved its new sustainability strategy, including guidelines to help navigate through the material changes associated with the transition to a low carbon economy and to promote climate change resilience and physical risks mitigation.

Following the new strategy and guidance, the company engaged with technical specialists from the Port of Antwerp International (PAI) and Deltares Consultancy.

A Working Group coordinated by the Port Administration and with the participation of the companies Gas Natural Açu (GNA), Ferroport and Vast Infraestrutura, subsidiary companies of Prumo Logística S.A. with operations at the port complex, worked together with Deltares and PAI technical consultants to enable a comprehensive assessment of the port's overall infrastructure and key operations. The main goals of the assessment were:

- Evaluate possible future climate scenarios.
- Estimate the vulnerability of key port operations under such scenarios and define potential adaptation strategies; and
- Anticipate potential upcoming challenges and required measures to face the physical risks identified.

METHODOLOGY

An overall assessment conducted by the Working Group introduced potential consequences of climate change and some of the challenges to be addressed. It then introduces a three-stage methodological framework to help Port of Açu planning on how best to adapt. The three-stage approach and its main goals are described below:

- **Phase 1:** Determine the current climate environmental conditions and compile the available projection of possible future scenarios (sea level, winds, waves and precipitation);
- **Phase 2:** Estimate the vulnerability of key port operations under future scenarios, an assessment based on the outcomes of Phase 1; and
- **Phase 3:** Implement recommendations arising from Phase 2, if and where needed.

This report presents the outcomes of the study Phases 1 and 2. The respective methodologies are presented below. Phase 3 was not required as an outcome of Phase 2.

Phase 1: Present and future climate regime at Port of Açu

This phase was focused on the definition of present and future climate conditions at the Port regarding sea level, winds, waves, and local precipitation. The characterization of the present regimes (i.e., mean and extreme) are based on observed patterns and trends over last years to decades. These assessments make use of datasets measured and provided by the Port, as well as a literature review and information from public sources. The following data were used:

- Tidal data measured at T1 and T2: the definition of the regime of sea level variations was based on the analysis of the data measured in the port.
- Wind data measured at T1: the measured data were compared with the reanalysis data (ERA5), including pointing out ERA5 limitations for higher intensity winds and suggesting a linear relationship for correction/calibration of the reanalysis data.

- Precipitation data measured at T1 and T2: were compared with ERA5 data for validation from the reanalysis database. In general, the comparisons proved to be satisfactory.
- Wave data: the characterization of the current regime was based exclusively on reanalysis data (ERA5) in deep waters. Internal comparisons were made with data measured in shallow water.

Future conditions were evaluated through a desktop study based on the IPCC Assessment Reports (AR) at global and regional scales, literature review and expert judgement, while considering information within the context of the project. At the time the study was developed, the latest AR6 was not yet (fully) available, thus the assessments used the preceding AR5 along with the latest scientific publications available. Later comparisons with the AR6 indicates satisfactory alignment, certifying the consistency of our results.

The time horizons considered in the assessments extend up to 2100, with scenarios evaluated for the Port region at three different timescales: 2040, 2070 and 2100. The emissions scenarios considered two Representative Concentration Pathways (RCP[1]) 4.5 and 8.5 (intermediate and worst-case climate change scenarios, as defined in the IPCC AR5):

- **RCP 4.5 - Medium emissions scenario / Intermediate Climate Change Scenarios:** This scenario represents a slight effort to reduce future emissions. Emissions continue to rise but less rapidly. Reduction strategies and policies have been implemented but have not been implemented at a large scale.
- **RCP 8.5 - High emissions scenario / Worst-case Climate Change Scenarios:** This scenario represents a 'business as usual' approach to emissions management with no changes made. The emissions under this predicted future continue to increase with no international climate policy or support shown. There will be no behavioral or policy changes made to reduce emissions and no uptake of low-carbon solutions.

Phase 2: Vulnerability assessments of key infrastructure and operations

This phase assesses the potential impact of climate change effects on Port of Açu. The analyses focus on interpreting the practical impact of projected changes in waves, wind, sea level and rainfall on port operations and structures of the port. In that way, the most important influential external drivers and the main port activities and assets have been considered in combination over the different timeframes up to 2100, allowing for evaluation of the most critical port aspects. For this, an extensive inventory of these key port assets and operations was developed, allowing the organization of the relevant information.

For Phase 2 the assessment considered the following key port assets and operations: Mooring and (un)loading operations; stability of breakwaters, pier and berths / quays; Port sedimentation and dredging volumes; and flooding of terminals yards and industrial areas. As outcomes, is the study presents an overview of potential future hazards per asset/operation, possible solutions and recommendations for follow-up assessments when applicable.

1. The Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report identified Representative Concentration Pathways (RCP) to model how the climate may change in the future based on the quantity of Greenhouse Gases (GHG) emitted. The RCPs capture the future trends and efforts to reduce emissions and predict how concentrations of GHG in the atmosphere will change in the future.

RESULTS

The results for each phase are presented in the following subsections.

Phase 1 – Climate projections

Seal Level: Maximum/extreme water levels under existing conditions (2020) are assumed to be in the order of 2.2 m above the Chart Datum. By 2100, median sea level change projections are +0.48 m and +0.78 m, considering RCP4.5 and RCP8.5, respectively.

Winds: Average wind speeds are projected to increase by approximately 10% by the end of the century. The presently available references indicate no significant effect of climate change on the maximum wind speeds regime (99th percentile) at the Port of Açu region within the 21st century.

Waves: According to recent publications, projected changes in seasonal mean Hs (significant wave height is defined as the average wave height, from trough to crest, of the highest one-third of the waves) near Port of Açu are marginal (up to 33%), and even less when considering the mean value of Hs over the whole year. Changes in mean wave period (~-1%) and mean wave direction (~1°) are projected to be small in the regions offshore the Port and are therefore deemed negligible in practice. The same applies for the more energetic Hs99 (significant wave height exceeded 1% of the time) and the extreme 1 in 100-year Hs.

Precipitation: Changes in annual mean precipitation are projected to be limited, in the order of -5% by the end of the century. Heavy rainfall events are projected to become more intense, with increase in the order of 2.5% and 20% by the end of the century relative to 2020 conditions, considering RCP4.5 and RCP8.5 respectively. Noteworthy, particularly wide confidence intervals (i.e., large uncertainty bands) applies to both annual mean and heavy precipitation projections.

Table 1 summarizes the changes in analyzed variables by the end of the 21st century, following the results of the literature cited within the report:

Table 1. Summary of Phase 1 results (Climate Changes projections).

Environmental Conditions	Global Carbon Cenarios (RCP)	Average Regime			Extreme Regime		
		2040	2070	2100	2040	2070	2100
	Intermediate	↑0,09m	↑0,26m	↑0,48m	⊖	⊖	⊖
	Worst Case	↑0,11m	↑0,38m	↑0,78m			
	Intermediate	+1% change in yearly mean speed	+4% change in yearly mean speed	+10% change in yearly mean speed	⊖	⊖	+2,0% change in highspeed winds
	Worst Case						
	Intermediate	⊖	⊖	-Mean Wave: negligeble -Significant wave Height; ↑ +3% winter, ↓ -3% summer	⊖	⊖	↑ +2,0% change in Significant wave Height
	Worst Case						
	Intermediate	⊖	↓ -2,5% in yearly mean preciptation	↓ -5,0% in yearly mean preciptation	⊖	Annual max. 1-day Preciptation: +2,5%	Annual max. 1-day Preciptation: +2,5%
	Worst Case					Annual max. 1-day Preciptation: +7,5%	Annual max. 1-day Preciptation: +2,5%

Mean Sea Level   Wind   Wave   Rainfall   ⊖ Smaler than changes by 2100 (this neglegible)

It must be highlighted that, especially for longer timeframes, climate projections have wide uncertainty bands. Future mitigation measures on greenhouse gases (GHG) emissions to be taken by society are unknown (i.e., RCP scenarios), which also adds to uncertainty bands on longer-term projections. The present monitoring campaign provides valuable databases to identify future extreme events and trends of changes, and therefore is recommended to be continued.

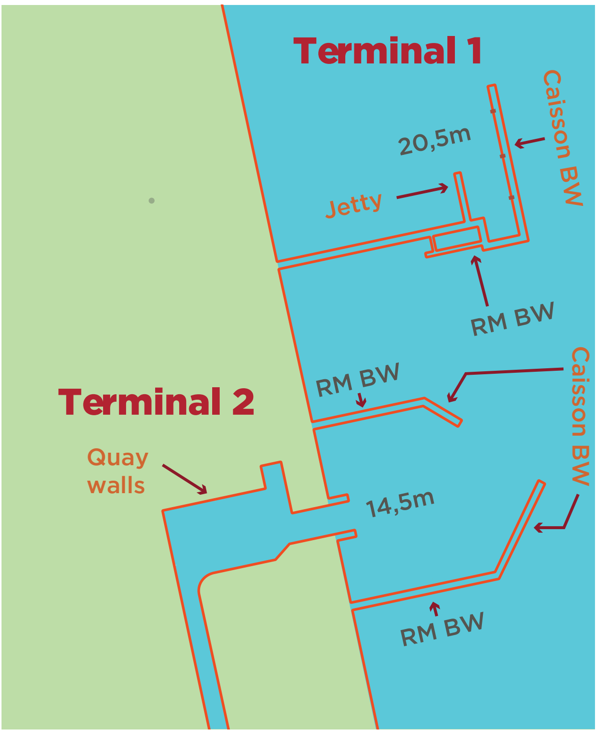
Phase 2 – Impacts to key port's operations and assets

The projections of changes in ambient conditions at Port of Açu due to climate change indicate that the port location is favorable, showing generally limited changes in such conditions relative to global mean changes. The most noticeable changes identified are expected to occur in mean sea level, wind, and rainfall conditions. On the other hand, most (off) loading operations will be mainly influenced by wave conditions – and to a smaller extent wind – and particularly those conditions are not expected to change much at the port site according to present-day climate change projections.

PORT MAIN STRUCTURES - STABILITY OF BREAKWATERS, PIERS, AND BERTHS/QUAYS

Given the small projected changes in wave conditions at the location of Port of Açu, the projected changes in sea level rise form the main influential effect of climate change on structure stability and performance. Wind and rainfall influences on such structures are generally not normative. No extensive studies or adaptation measures are expected to be needed on the short term (decade) regarding the main port structures in response to climate changes effects. Figure 2 illustrates the types of structures at T1 and T2:

Figure 2. Types of structures at Terminal 1 and 2



The caisson breakwaters (T1 and T2) and rubble mound breakwaters (T2) designs have incorporated sea level rise and wave regime changes into the design as described in Acciona (2012a, 2012b). The same cannot be categorically stated for the Pier (T1), rubble mound breakwater (T1) and quay walls (T2), as the design reports were not available for analysis in the present study. In the next section some recommendations are made.

- **Hydraulic stability primary armour layer**[1]
  According to present information and insights, different parts of rubble mound structures at the port will be influenced by sea level rise in different ways: the front armour will not be influenced, the stability of the toe structure will increase and only the stability of the back-side armour might be negatively influenced by sea level rise (i.e., in case of excessive overtopping following sea level rise). Excessive overtopping leading to instability of the back-side armour is not expected to become an issue in the rubble mound sections of T2 before 2070+.

1. Primary armour: large rock grading or concrete units that form the upper layer of the slopes of rubble mound breakwaters, providing stability under the design wave forces.

- **Hydraulic and geotechnical stability caisson breakwaters**
  Given the projected small changes in wave conditions under climate change for the port location, the wave loads on the vertical face of the caisson breakwaters will still have approximately the same maximum value projected. However, the vertical level where this maximum wave load will act on the structure will shift upwards along with sea level rise. This will then influence the geotechnical stability, i.e. the overturning resistance of the caisson breakwater.
- **Wave overtopping rubble mound and caisson breakwaters**
  Caisson breakwaters at the port are expected to mainly experience a different height level at which wave loads will act on such structures, while the wave loads themselves may remain practically unchanged (assuming wave conditions today are not depth-limited). This has an influence on the sliding and overturning stability of those caissons and on wave forces acting on the additional structures at the top of the caissons.
- **Wave (slamming) loads acting on the jetty deck**
  Net freeboard of the deck reduces with sea level rise and may result in substantial wave slamming loads. Decks of the jetties at Port of Açu have been designed at an elevation to avoid wave crest influences completely – based on the mean water level present at the time of design – then the assumed height safety margin in the design should be revisited to interpret the possibility of wave impacts (slamming) in the future as the mean sea level rises over time.
- **Hydraulic and geotechnical stability quay walls**
  Quay walls of the port may be influenced by sea level rise once it exceeds the design water level. This is because of less effective structural ground anchors when groundwater levels rise along with the mean sea level. Moreover, along with sea level rise beyond values included in the original design, waves may overtop the quay structure, leading to operational issues and possible structural damage.

PORT OPERATIONS - MOORING AND (UN)LOADING

Mooring and (un)loading operations in Port of Açu are expected to be most critically influenced by wave conditions and to a smaller extent by wind, water levels and currents. Therefore, considering the projections of Phase 1, the study concluded the following main findings:

- **Mean sea level**
  Reduce freeboard and may lead to flooding. Quay related aspects such as vertical fender positions may require adjustments. Presently available projections indicate that highlighted attention points will not become critical on the shorter term (possibly 2070+).
- **Wind**
  The conditions may mostly impact the operation of certain cargo handling equipment, maneuvering vessels and moored vessels to a smaller extent, particularly bulk vessels. No actions required on short-term.
- **Waves**
  In the presently available projections of climate change effects up to 2100 particularly wave conditions show a small change. This applies to heights, periods, and directions. This means that the quay-side port operations considered in this phase are not expected to be severely impacted by climate change effects. Port may therefore focus on optimizing the present-day port conditions and operations, especially if those are indeed mostly influenced by wave conditions (T1 and/or T2).

EXPECTED IMPACTS OF RAINS EVENTS

Under present-day climate conditions rainfall events cause disruptions in (off)loading activities at Port of Açu. The median projections indicate a reduction in the number of rainy days per year. However, given the associated uncertainty bands in projections, the possibility of an increase cannot be disregarded.

The storage and drainage infrastructure for the contaminated rainwater at the T-MULT terminal does occasionally already nearly reach its maximum capacity under present-day. This shows that there is little margin in the runoff collection system to deal with any future increases in rainfall. This means that close monitoring and possible actions already on the short-term are recommended.

Rainfall extremes are projected to increase in the future with 5 to 15% (2070 and 2100, respectively), although associated uncertainty bands are rather wide – even in the shorter term. This means that the timing and intensity of change is unknown. Therefore, it is possible that the current maximum storage capacity at T-MULT will not be sufficient in the future, to an extent depending on how of the foreseen climate change scenarios will develop.

PORT SEDIMENTATION AND DREDGING VOLUMES

Understanding of the present-day coastal sediment dynamics based on the available information is essential starting point for any analysis, irrespective of climate change. The study concluded:

- **Terminal T1:** a primary driver of present-day sedimentation is likely the relatively deep and sheltered basin, in which suspended fine sediment (plumes) can easily settle and deposit. An additional component is possibly the transport of local seabed sediment that is interrupted by the dredged areas (especially in areas where flow contraction occurs). The relative contributions of these components could however not be verified with the available data.
- **Terminal T2:** the main drivers of present-day sedimentation are likely the uptake of transport of local seabed sediment that is interrupted by the shipping channel (especially near the port mouth where flow contraction occurs, and a 'sediment bump' is located), and the tidal exchange facilitating the ingress and settling of fine sediment in the port basin (leading to fluffy sediment deposits). The observed changes in shoreline positions are currently not contributing to sedimentation in the dredged areas.
- **Mean sea level:** Water depths will increase along with sea level rise. Overall, this will likely lead to a proportional reduction in ambient flow velocities, which in turn could lead to both a reduction in plume concentrations and in sediment transports at the seabed. Furthermore, due to the increase in water levels, the level of lowest astronomical tide will increase. In turn, given a pre-defined depth, this will lead to a reduction in required dredging levels. The potential reduction in maintenance dredging may be as high as several 10's of percent by 2100.
- **Winds:** The increasing wind speeds and more persistent southerly directed flow conditions and more effective spreading of fine sediment plumes from the north & locally some slight uptake of sediment transport may result in somewhat increased sedimentation. However, these effects are expected to be smaller compared to the changes due to sea level rise
- **Waves:** Reported potential changes in the wave climate are considered subordinate to be included in an assessment of potential effects on port sedimentation, even for the year 2100, as no significant influence on sedimentation is expected.

- **Precipitation:** The potential changes in precipitation could lead to a significant increase or decrease in river discharges and (fine) sediment loads from the Paraíba do Sul River. As this is considered one of the main drivers of sedimentation in Port of Açu, monitoring how this uncertain component will develop into the future is recommended.

PHASE 2 SUMMARY

No significant risks to key port assets and operations are identified for the short-term (decade) related to climate change at port area. Presently available projections indicate generally mild effects of climate changes to the analyzed parameters also towards the end of the century (2070+), limiting the consequences to operations and infrastructure. However, climate projection uncertainties become wider over the longer term, making monitoring and update assessments of prime importance within the next decades.

Table 2 relates climate projections (hazard) with the port's critical assets and operations (vulnerability).

Table 2. Summary of Phase 2 results: Climate projections and vulnerability assessment

Sea Level

PROJECTIONS 2100:
0,48m - 0,78m sea level rise

Vulnerability assessment:

• No significant risks to key port assets and operations at short or longer-terms were identified.

• Overall influence of rainfall patterns at Paraíba do Sul watershed on sediment output – affecting the need for maintenance dredging –, and water inflow at the region – potentially leading to floods. Further studies are necessary to investigate these dynamics.

Waves

PROJECTIONS 2100:
Significant wave Heigh: +3% winter, -3% summer

Vulnerability assessment:

• Projected changes are very small - only toward 2100 reaching noticeable effects.

Existing operational wave limits should therefore be equally met in the future as they are now.

Wind

PROJECTIONS 2100:
10% increase in yearly mean speed and 2% increase in extreme events

Vulnerability assessment:

• Need close monitoring of cargo handling sensitive to wind and vessels maneuvering - may require adaptation actions on long term.

Rainfall

PROJECTIONS 2100:
5% decrease in yearly mean preciptation with increase of 2,5% - 20% on extreme events

Vulnerability assessment:

• Dry bulk terminals more vulnerable to extreme rainfall events (i.e., contamined runoff).

• Close monitoring on dry bulk terminals necessary and measures may be required on short term.

Table 3 summarizes the main results based on the climate-change related aspects with shorter-term and longer-term. The indicative hazards represent the changing driving conditions (i.e., sea level, winds, waves and precipitation). The vulnerability of specific operations and infrastructure components is related to their sensitivity to changing conditions and the adaptative capacity. Potential risks are proportional to the product of hazards and vulnerability. Classifying hazards, vulnerability and risks in categories considering the different forcing and port components is inevitably subjective.

Generally, the uncertainty and/or strength of the hazards increases from the shorter (decade) to the longer term (2070+). When combined with the vulnerability of specific operations or infrastructure components, this typically leads to increased potential risks associated with time horizons further into the future. If in the future the present projections prove to have underestimated the changes in ambient conditions, such a sensitivity analysis will be useful to identify the potential risks under such, albeit presently unexpected, more adverse conditions.

Table 3. Summary of Phase 2 results: Vulnerability assessment

Climate-change related aspects		Shorter-term (decade)						Longer-term (2070+)					
		Hazard	Vunerability	Sea level	Winds	Waves	Precipitation	Hazard	Vunerability	Sea level	Winds	Waves	Precipitation
Workability and downtime	Reduce freeboard (flooding, quay-related aspects)	o	**	Neutral	Not applicable	Not applicable	Not applicable	*	**	Close monitoring	Not applicable	Not applicable	Not applicable
	Wave-induced forces and motions on ships	*	***	Not applicable	Not applicable	Close monitoring	Not applicable	**	***	Not applicable	Not applicable	Actions possibly required	Not applicable
	Wind-induced forces and motions on ships	*	o	Not applicable	Neutral	Not applicable	Not applicable	**	*	Not applicable	Close monitoring	Not applicable	Not applicable
	Cargo handling (sensitive to wind)	*	***	Not applicable	Close monitoring	Not applicable	Not applicable	**	***	Not applicable	Actions possibly required	Not applicable	Not applicable
	Manoeuvring	*	***	Not applicable	Close monitoring	Close monitoring	Not applicable	**	***	Not applicable	Actions possibly required	Actions possibly required	Not applicable
Stability of main port structures	Hydraulic stability primary armour layer	o	**	Close monitoring	Not applicable	Neutral	Not applicable	*	**	Close monitoring	Not applicable	Close monitoring	Not applicable
	Hydraulic and geotechnical stability caisson breakwaters	o	**	Neutral	Not applicable	Neutral	Not applicable	*	**	Actions possibly required	Not applicable	Close monitoring	Not applicable
	Wave overtopping rubble mound & caisson breakwaters	o	**	Neutral	Not applicable	Neutral	Not applicable	*	**	Actions possibly required	Not applicable	Close monitoring	Not applicable
	Wave (slamming) loads acting on the jetty deck	o	***	Close monitoring	Not applicable	Neutral	Not applicable	*	***	Actions possibly required	Not applicable	Close monitoring	Not applicable
	Hydraulic and geotechnical stability quay walls	o	**	Close monitoring	Not applicable	Not applicable	Not applicable	*	**	Actions possibly required	Not applicable	Not applicable	Not applicable
Port sedimentation and dredging volumes	Local conditions for sedimentation	o	**	Neutral	Not applicable	Neutral	Not applicable	*	**	Beneficial	Not applicable	Close monitoring	Not applicable
	Regional transport towards port	*	*	Not applicable	Neutral	Not applicable	Not applicable	**	*	Not applicable	Close monitoring	Not applicable	Not applicable
	River supply of fine sediments	**	*	Not applicable	Not applicable	Not applicable	Close monitoring	**	*	Not applicable	Not applicable	Not applicable	Close monitoring
	Beach-related sedimentation	o	**	Not applicable	Not applicable	Neutral	Not applicable	*	**	Not applicable	Not applicable	Close monitoring	Not applicable
Expected impacts of rain events	(Un)loading operations (general cargo, iron ore)	**	***	Not applicable	Not applicable	Not applicable	Actions possibly required	***	***	Not applicable	Not applicable	Not applicable	Actions possibly required
	Drainage at terminals with contaminated runoff	**	***	Not applicable	Not applicable	Not applicable	Actions possibly required	***	***	Not applicable	Not applicable	Not applicable	Actions possibly required
	Drainage at other terminals	**	*	Not applicable	Not applicable	Not applicable	Close monitoring	***	*	Not applicable	Not applicable	Not applicable	Close monitoring

Potential risks - Beneficial | Actions possibly required | Close monitoring | Neutral | Not applicable

Strength and/or Uncertainly: o * ** *** (Less → More)

ADAPTATION MEASURES AND RECOMMENDATIONS

After a detailed analysis of all Phase 2 results, the study concluded that adaptation measures are not necessary in the short and medium term (so Phase 3 was dismissed). The projects of part of the structures that comprise the Port of Açu have already considered variations related to climate change and the management of the port. It follows international standards of control and performance, these aspects were decisive in assessing the need to adopt adaptation measures.

Among the aspects related to resilience to climate change, the following measures already implemented or under implementation stand out as strengths of Port of Açu:

- **Structural measures:** structures already designed with climate change standards, VTS, maintenance dredging planning, improvement of drainage systems, inclusion of sea level rise projections in future infrastructure designs.
- **Non-structural measures:** metocean monitoring and alerts systems, crises and emergency management and response, predictive maintenance programs, extreme events management, adoption of good work practices, stakeholder engagement in planning flood management options, port's strategic plan and the climate change adaptation planning.

Although there is no foreseeing need of adaptation at Açu, some recommendations are made to improve ports' operational resiliency. With the recommended actions the port is expected to be able to maintain and improve its operability and performance on the short-term, while remaining vigilant and prepared for potential changes in ambient conditions in the future.

A set of recommendations to be implemented to increase port climate resilience:

- Continue and improve data collection of relevant parameters (wind, waves, water levels, rainfall). Wave measurements should be extended to include infragravity waves.
- Verify different sources of offshore present-day climatic information (e.g., ERA-5, NOAA, or commercial databases), incorporate the datasets measured over the last years within the port and ensure that the most recent, consistent, and high-quality dataset for a representative output location (and water depth) is applied in further port development projects, together with considering projected future changes in conditions.
- Analyze within coming years the hydraulic loading conditions used in the original designs of the T1 jetty, the rubble mound breakwater in T1 and the quay walls of T2, whereby focusing on the impact of sea level rise. These assessments should provide insight about the vulnerability of these structures (presently uncertain due to the limited available information) and therefore better define the potential longer-term risks related with climate change effects.
- Perform additional measurements to increase further understand the sediment dynamics in and around the port area and associate with the studies developed by Fundação Coppetec (2021).
- Specifically assess the Paraíba do Sul River influence on the region (sediments contribution and floods).
- Investigate potential measures to reduce port siltation (regardless of climate change effects). These may lead to large reductions in yearly maintenance dredging volumes and operational costs.

- Investigate whether the ‘sailing through mud’ concept is a suitable approach for the port. If feasible and applicable, that too may result in large cost savings for the Port.
- Incorporate the results in future projects design.
- Update the assessments described in this report every 10-20 years to incorporate possible port expansions, operational changes, and to verify trends and developments, as experience with port operations evolve, more measurement data become available and trends in changes in relevant parameters will become more outspoken and verifiable.

CONCLUSIONS

The studies carried out assessed Port of Açu vulnerability to future climate scenarios and stablished the needs for adaptations, as part of port's Climate Change Management.

The results of these studies, summarized in this report, show that currently available projections indicate generally limited changes in environmental climatic conditions in the coming decades, concluding that the location of the port can be considered favourable from a climate change point of view. The results also indicate that possibly more relevant changes are projected to occur in the long term (2070+) in mean sea level, wind, and precipitation conditions.

No new adaptation measures were anticipated to be necessary in the short and medium term. However, some recommendations are made to improve the resilience of port operations. With the recommended actions, it is expected that the port will be able to maintain and improve its operability and performance in the short term, remaining vigilant and prepared for possible changes in environmental conditions in the future.

The described assessments shall be updated every 10-20 years to incorporate possible port expansions, operational changes, and to verify trends and developments. This is especially relevant as more measurement data become available, trends of changes in relevant parameters will become more outspoken and verifiable, and future climate projections become more detailed and accurate.

The results obtained will be incorporated into future port planning, providing technical grounds for new investments, engineering designs, and enhance port resilience. The recommendations will be integrated in the corporate risk management, where the implementation will be monitored to guarantee the follow up and a proper governance.

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GLOSSARY:

AR	IPCC's Assessment Report
ERA5	Atmospheric reanalysis of the global climate
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration (USA)
RCP	Representative Concentration Pathways
T-MULT	Multicargo Terminal at Port of Açu
T1	Terminal 1 at the Port of Açu
T2	Terminal 2 at the Porto of Açu
VTS	Vessel Traffic Services